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THE GLACIERS AND GLACIATION OF ALASKA[1]

INTRODUCTION

NOTWITHSTANDING the great area of Alaska, the ruggedness and inaccessibility of a large part of the glaciated region, and the briefness of the period of exploration, we are already in possession of a large body of fact with regard to the glaciers and glaciation of our northern territory. The researches of Wright,[2] Russell,[3] Reid,[4] Gilbert,[5] Davidson,[6] Dall[7] and others have given us much valuable information concerning the coastal region; and the many expeditions by Hayes,[8] Brooks, and various other members of the United States Geological Survey[9] have added ma-

[1] Presidential address before the Association of American Geographers, at the Washington meeting, December 29, 1911.

[2] Wright, G. F., "The Ice Age in North America," New York, 1891, chapter III., pp. 36–66.

[3] Russell, I. C., "An Expedition to Mount St. Elias, Alaska," *Nat. Geog. Mag.*, Vol. 3, 1891, pp. 53–203; "Second Expedition to Mount St. Elias," Thirteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1892, pp. 1–91.

[4] Reid, H. F., "Studies of Muir Glacier, Alaska," *Nat. Geog. Mag.*, Vol. 4, 1892, pp. 19–84; "Glacier Bay and its Glaciers," Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1894–95, pp. 415–461.

[5] Gilbert, G. K., "Glaciers and Glaciation," Harriman Alaska Expedition, Vol. III., New York, 1904.

[6] Davidson, G., "The Glaciers of Alaska," Trans. and Proc. Geog. Soc. Pacific, Vol. III., Ser. II., June, 1904, 98 pp.

[7] Dall, W. H., U. S. Coast Pilot, Pacific Coast, Part I., Alaska, 1883, Washington, D. C.

[8] "An Expedition through the Yukon District," *Nat. Geog. Mag.*, Vol. 4, 1892, pp. 117–159.

[9] Mainly published in annual reports, bulletins and professional papers of the U. S. Geological Survey.

terially to this knowledge, and have extended the area of observation to the interior. Thus, even though there is yet much to learn, the knowledge that we now possess is sufficient to warrant a discussion of the general phenomena of Alaskan glaciation; and since this is the object that has been most in my mind during the past six years, it has naturally appealed to me as the most fitting topic for the presidential address which I am called upon to give.[10]

THE EXISTING GLACIERS

Condition of the Existing Glaciers

Alaskan glaciation is, and has been, of the mountain type. That is to say, mountain snow fields have shed into mountain valleys, and through these the glacier ice has flowed to lower levels, in some cases even to the sea. Numerous glaciers, and in former times a still greater number, have flowed beyond their valleys and spread out fan-shaped at the mountain base, giving rise to the type of *piedmont* glacier which Russell has made known to us through his studies of the Malaspina glacier.

The main region of existing glaciers occupies a roughly semicircular area sweeping from the southern boundary of Alaska, northward, westward and southwestward, toward the Aleutian islands. From either end of this zone both the number and the size of the glaciers increase, and the elevation of their termini decreases, attaining maximum development near the center of the semicircle that surrounds the head of the Gulf of Alaska. Altogether there are at least 47 tidal glaciers in this zone, the southeasternmost being the Le Conte Glacier, just north of Wrangell, and the westernmost McCarty Glacier on Kenai peninsula. Toward the ends of the glacier zone there are few and scattered instances of tidal glaciers; but in the central part of the zone they are numerous, and, where topographic conditions favor, are close together. Thus in Glacier Bay there are at least twelve tidal glaciers; in Yakutat Bay three; and in Prince William Sound twenty.

How many glaciers there are in this coastal area can not be even approximately estimated; but, counting large and small, tributaries and main ice streams, they are certainly to be numbered by the thousand. These vary in size from tiny ice masses in cirques, to valley glaciers two or three miles in breadth and thirty or forty miles in length; and up to the great Malaspina Glacier whose area is estimated to be 1,500 square miles. From the Kenai peninsula to Cross Sound a very large proportion of the seaward face of the mountains is covered with snow and ice, and glaciers exist in a majority of the valleys, deeply filling most of the larger ones. From Controller Bay to Cross Sound a succession of piedmont glaciers and expanded bulbs of individual glaciers spread out between the mountain base and the sea. A journey along this coast is, therefore, a constant glacial panorama.

Distribution of Existing Glaciers

The mountains which fringe the Alaskan coast as a continuous barrier, as far west

[10] The personal field work upon which this address is in part based was done in 1905 and 1906 under the auspices of the U. S. Geological Society; and in 1909 and 1911 under the auspices of the Research Committee of the National Geographic Society. To both of these bodies acknowledgments are due for the generous financial support given. The last two expeditions have been under the joint leadership of Professor Lawrence Martin and myself; and I wish especially to acknowledge my indebtedness to my colleague in two seasons of work, who was also an assistant on the first expedition. We have worked and observed together and have freely discussed all problems which have arisen. The results of our joint work are used in this address, as are also the results of other students of Alaskan glaciation.

as Cook Inlet, attain their greatest elevation in the St. Elias-Fairweather Range where peaks rise 12,000 to 15,000 feet, 18,000 feet in Mount St. Elias, and 19,540 feet in Mount Logan. Here, naturally, the glaciers are largest, for from this central area the general elevation, as well as the heights of the peaks, diminishes toward both the southeast and the west.

Back from the coast, and roughly parallel to the curving mountain barrier around the head of the Gulf of Alaska, is another lofty range sweeping northward from the Alaska peninsula, then eastward and southeastward. In its highest part, called the Alaska Range, are numerous lofty mountain peaks, including Mount McKinley (20,300 feet), the highest mountain in North America. Between this interior range and the coastal mountains is a broad depression occupied by Cook Inlet in the south and the Copper River Basin in the east; but in the extreme east the area between the two mountain ranges is mainly occupied by the great volcanic group known as the Wrangell mountains, whose peaks attain elevations of from 14,000 to 16,000 feet.

Naturally these lofty mountains of the interior are also the seat of numerous and large glaciers. But neither here, nor on the inner face of the coastal mountains, is there so full a development of ice and snow as along the coast. The snow line is higher, the glacier ends are all necessarily well above sea level, and the piedmont type of glacier is absent. The glaciers are essentially confined to the mountain valleys, though some extend to the mouths of the valleys, and a few spread slightly beyond them. It must not be inferred that the glaciers of the interior are insignificant either in size or in number; merely that they suffer in comparison with their larger neighbors nearer the sea. Were they the only glaciers of Alaska they would themselves attract wide attention because of their number and size. Besides being dwarfed by comparison with the coastal glaciers, these in the interior have the disadvantage of remoteness and relative inaccessibility. They are, therefore, far less well known than the glaciers of the coast.

The difference between the glaciers on the two sides of the coastal mountains may be typically illustrated by the Valdez-Klutena system, two glaciers which descend in opposite directions from a common divide in the Chugach mountains, at an elevation of 4,800 feet. The Valdez Glacier, descending on the seaward side of the mountains, is 19 miles long and ends at an elevation of 210 feet, while the Klutena Glacier, descending toward the interior, is only 6 miles long and ends at an elevation of 2,000 feet. A similar difference is observed in the Nizina and Chisana glaciers, which descend from a common divide at an elevation of 8,000 feet in the Wrangell Mountains, the former descending on the side facing the sea and therefore being much longer than the Chisana Glacier, which flows toward the interior. The total length of the two ice streams is about 47 miles.

Beyond the Alaska Range, although there are numerous mountain and plateau areas of considerable elevation, lying far to the north, there is a general absence of existing glaciers, the only exception, so far as known, being on the Arctic slope of the Endicott Mountains (5,000–8,000 feet). Here, in the summer of 1911, Phillip S. Smith and A. C. Maddren[11] observed a number of small valley glaciers.

Explanation of the Distribution of the Glaciers

The distribution of glaciers in Alaska is not difficult to explain. That they are so

[11] Personal communications to the author.

extensively developed along the seaward face of the coastal ranges is plainly due to the fact that the prevailing winds are from the ocean, and that in blowing over the warmed waters of the Gulf of Alaska a large amount of vapor is moved forward and precipitated in the form of snow upon the lofty mountain barrier. It is where the coastal barrier is most complete and highest that the snowfall is heaviest and the development of glaciers greatest. The annual precipitation varies greatly, records of from 100 to 190 inches having been obtained at stations along this coast; but there is no knowledge as to the precipitation among the lofty mountains, excepting the knowledge that it is very heavy and mainly in the form of snow.

In a region where from 10 to 40 feet of snow falls each year at sea level, there must be exceedingly heavy snowfall at elevations where the precipitation is all in the form of snow. As an indication of the vast snowfall among the mountains, reference may be made to Schrader's observation of from 8 to 12 feet of snowfall on Valdez Glacier during a week late in April and early in May, 1898. By such heavy precipitation the snowline is depressed to levels of 2,500 to 3,500 feet on the seaward face of the mountains, and to even lower levels back in the mountains where the local climate is cooled by the chill of the surrounding areas of snow and ice.

Since the damp winds precipitate so much vapor in crossing the mountain barrier, there is a deficiency for precipitation on the inner slopes of the mountains and on the ranges further inland. Moreover, such winds as sweep into interior Alaska from either the Arctic Ocean or Bering Sea bear but a limited vapor burden, since the water of these seas is cold in summer and more or less completely ice-covered in winter. Records at Eagle give a rainfall of only 11.35 inches; but the precipitation is doubtless higher toward the west and in the lofty mountains.

The winters of the interior are prevailingly clear and cold with moderate snowfall—for example, only 2 or 3 feet of snow falls in the Copper River Basin; but in spring and summer the temperature is so high that the snow quickly melts even well up on the mountain slopes. Thus, even in the neighborhood of the Arctic Circle a plateau from 3,000 to 6,000 feet in elevation is completely free from snow in summer, as is also a large portion of the Endicott mountains; and, whereas the snowline on the seaward face of the St. Elias range is about 3,000 feet, it is more than twice as high as that in the interior three or four hundred miles further north. The exact elevation of the snowline in the interior can not be stated, and indeed it must vary greatly from place to place. In general, however, it is above 6,000 feet.[12]

This rise in the snowline toward the north is interesting as showing how important the element of precipitation is. The snowline is lower and the glaciers are larger where the mean annual temperature is high and the precipitation is heavy, than in the much colder climate further north where, however, precipitation is light and the short summers are warm. A similar variation is noticed in the coastal mountains where the snowline is considerably higher along the inner fiords than on the outer coast where the precipitation is heavier. It is to be noted, however, that in the latter place not only is there a greater depth of snow to be melted, but in the neighboring lofty mountains there are

[12] Oscar Rohn (Twenty-first Annual Report U. S. Geological Survey, pt. 2, 1899–1900, p. 413) states that on September 1 the snowline was 7,500 feet in one part of the Wrangell Mountains, and was then descending.

broad expanses of snow and ice which serve to retard summer melting.

In the distribution of its glaciers Alaska presents a striking contrast to that part of Europe in the same latitude. There are no glaciers in southern Scandinavia, in the latitude where, in Alaska, the glaciers are largest; and while in Norway there is an increase in glaciation northward, in Alaska there is a decrease. In Norway the influence of latitude is permitted to exert its normal effect; but in Alaska the influence of latitude is effectually counterbalanced by variations in topography and in the vapor content of the air. This contrast may have some significance in the explanation of the development of extensive ice sheets in northwestern Europe and northeastern America, while northern Asia and northwestern North America, in the same latitude, were free from continental glaciation.

Ice Flooded Valleys and Through Glacier Systems

Only by individual description of a large series of instances would it be possible to adequately portray the varied characteristics of the Alaskan glaciers. As in the Alps, Caucasus and Himalayas, the valley glacier is the normal type, but with many variations in form, size and rate of motion. From the lofty peaks a series of radiating glaciers usually spread outward; but throughout much of the mountain area there is a complex of ramifying glacier systems. Nowhere, so far as known, is there a development of the ice cap condition such as is found in Norway, Spitzbergen and Iceland, for the mountains are so lofty and rugged that the valley slopes serve to drain away the surplus snow that falls upon the steep mountainsides.

Still the snowfall is so heavy, especially near the coast, that, in the process of drainage, the valley systems are deeply filled with ice in spite of the ruggedness and high elevation. In the area of greatest glacier development, in the St. Elias region, the extent of snow and ice is so great as to have led Russell to speak of it as "a vast snow-covered region, limitless in expanse, through which hundreds and perhaps thousands of barren, angular mountain peaks projected," and to compare it to the "borders of the great Greenland ice sheet." How deeply these vast glacier systems fill the valleys we have no means of telling; nor can we even estimate the aggregate length or area of the maze of ice streams that flood the mountain valleys. In a region where dozens of glaciers are known to have lengths of from twenty-five to forty miles, it can not be doubted that the aggregate length of the ice streams is thousands of miles, and that the total area of snow and ice amounts to tens of thousands of square miles.

Although the vast bulk of ice that is slowly draining away the snow that falls among the Alaskan mountains maintains the valley glacier condition rather than developing an ice cap, it gives rise to an intermediate condition, as Russell's description intimates. That is, although the mountain summits are not flooded, the valleys are. For example, one may start from Yakutat Bay and, traveling up one of the large glaciers, rise above the snowline by a moderate grade and finally reach a flat, snow-covered divide, beyond which, also with moderate grade, a descent leads down a glacier flowing in the opposite direction. Or, to the right or the left, also over flat, snow-covered divides, an easy route is open down other glaciers. In this way one may travel for scores of miles, going from one valley to another and from one glacier to another, but crossing only broad, flat snow divides. So deeply is the region submerged

by ice that both the valley bottom topography and the valley head divides are so smoothed out as to give rise to a continuous, connected glacier system with drainage in different directions from flattish divides; but both the divides and the glacier distributaries from them are walled in by steeply rising mountains, each portion of the system having the characteristics of the valley glacier. For such a complex I have proposed the name—*through glacier system.*

The through glacier condition is rendered possible by presence of low divides, and it is believed that, in general, these have originated during an earlier period of more intense glaciation when the snow and ice accumulated to much greater depths than now and flowed across the divides, lowering them by glacial erosion.

In its main essential characteristics, even the through glacier system belongs in the class of valley glaciers; and the valley glacier phenomena in Alaska are in the main the same as those with which we are already thoroughly familiar from the studies of glaciers in the Alps, Himalayas and other mountain regions. As compared with those of the Alps, the larger valley glaciers of Alaska are far greater, and this naturally introduces corresponding differences in form and behavior; but these are differences in detail rather than in underlying principles, and may therefore be dismissed in the present discussion.

At their termini some of the Alaskan glaciers present features not found in the Alps, notably the termination in tidal cliffs from which icebergs are discharged, and expansion on the land to form piedmont bulbs and piedmont glaciers. At a period of former expansion of glaciers, the piedmont condition was present in the Alps also; and the present Alaskan glaciers are more comparable with those expanded Alpine glaciers than with their shrunken descendants of to-day.

Development of the Cascading Glacier

As in other mountain regions, the present-day Alaskan glaciers, though very large, are mere remnants of a former far greater system, occupying the lower levels of valleys which were profoundly deepened by erosion when the former greater ice masses occupied them. Accordingly, the surface of the present-day glaciers, in the main valleys, is very often well below the level of the surface of the tributaries, which therefore descend with steep slope at their lower ends. There is every gradation, from the accordant junction of tributary and main glaciers, to the ice step, or "bench," where the two join; to the cascading descent of the tributary as it joins the main ice stream; and to the former tributary, now cut off from junction with the main glacier, but cascading toward it in its lower portion where it passes out of its hanging valley and descends the steepened valley slopes in a series of broken steps like a great frozen waterfall. This condition is so well developed in Alaska, and is so widespread and so characteristic, both in form and cause, that the descriptive name *cascading glacier* has been proposed for it.

Development of the Ablation Moraine

Glacial erosion, which has produced extraordinary topographic change in the Alaskan mountains, has, among other results, given rise to very steep valley walls. Such steep slopes, produced by ice erosion during the higher stage of the glaciers, are now, on exposure to the air, in a state of instability under the attacks of the agents of subaerial denudation. Therefore, they weather rapidly, and from them rock falls and avalanches frequently descend. This

rock, mixed in the snow out of which the glacier is made, and spread out over its surface, is concentrated by ablation in the dissipator until the ice surface often becomes completely covered by a sheet of moraine, to which the name *ablation moraine* has been given. It is naturally upon the lower ends of the glaciers that the ablation moraine is most extensively developed; but in some instances it extends far up the valleys, almost or quite to the snowline. Then the valley glacier looks so little like an ice stream that it may not be recognized as one by the casual observer; and on some of the Alaskan maps such glaciers have found no place.

Since only a portion of the Alaskan glaciers bear ablation moraine it is evident that special conditions are demanded for its development. It is best developed on those ice tongues with steep walls and steep heads, whose width is not too great for avalanches to spread out well toward the middle, and whose valley walls are of a friable rock. In proportion as these conditions vary, the extent of the moraine sheet also varies. Normal weathering and the spread of the falling rock through the snow fields and over the ice tongues are undoubtedly sufficient to account for the formation of a sheet of ablation moraine; but the excessive development of such moraine in some portions of the Alaskan region may perhaps be due in part to the aid which earthquake shaking gives in the downthrow of avalanches from the glacier valley walls. When a glacier bearing a sheet of ablation moraine has melted away, it leaves not only a deposit of till with scratched stones, but overlying this a sheet of coarse, angular fragments and weathered materials. Such deposits are to be expected in mountain regions of former glaciation.

Influences Modifying Rate of Recession of Glaciers

The ablation moraine is one of the factors influencing the position and rate of recession of glacier fronts; another factor is the position of the front, whether on the land or in the sea; for in the latter case recession is far more rapid and active than in glaciers ending on the land. For example, in the St. Elias region, while the Guyot, Seward, Marvine, Lucia, Yakutat and other glaciers that end on the land have spread out from one to twenty miles beyond the mountain front, the great, rapidly-moving tidal Hubbard Glacier, near by, ends at the head of Disenchantment Bay, ten miles or more back among the mountains. Both tidal and non-tidal glaciers are exposed to surface wastage by melting and evaporation; but the tidal glaciers are further exposed to the effective attack of the salt water which quickly removes the ice fragments that fall into it. Therefore, other things being equal, the tidal glacier will naturally terminate farther back among the mountains than non-tidal glaciers of similar character.

Glaciers advancing into rivers are also actively attacked, as is illustrated by the Childs and Miles glaciers in the Copper River Valley, and by glaciers in the Alsek Valley. To a lesser degree the same tendency to more rapid retreat is present in glaciers that terminate in lakes, as the Yakutat Glacier does.

Among ice tongues ending on the land there is great difference in the rate of wastage according to exposure and elevation; but even more important is the protective influence of the cover of ablation moraine. This finds best illustration in those glaciers which spread out fan-shaped at the mountain base, attaining a state of stagnation or semi-stagnation along their margins. Here, near sea level, in a rainy,

temperate climate, wastage by ablation would normally be active, and if the ice supply failed the glaciers would rapidly recede. But the sheet of ablation moraine that develops serves as a blanket against both melting and evaporation, and the rate of wastage so decreases with increase in thickness of the morainic cover that there finally comes a condition of almost complete protection. When the moraine cover is no longer subject to frequent undermining and slumping, vegetation finds a foothold, and ultimately even a mature forest may spread over the moraine that blankets the ice. Glacier recession under such conditions almost ceases and an ice terminus may remain for scores of years without notable change, even though ice supply is completely cut off.

In view of the fact that a protected ice terminus may remain so long in one position, it follows that the piedmont condition is not necessarily proof either of recent expansion or of a continuance of ice supply after expansion. Indeed, there is reason to believe that the piedmont glaciers, and the piedmont bulbs of individual glaciers in Alaska have been formed by expansion at entirely different periods. In some the supply is still being maintained and the ice terminus is kept in place by the essential balance between supply and wastage. This seems clearly to be the case in the greater part of the Malaspina Glacier; but elsewhere there is evidence that the expansion occurred during an earlier period of advance, and that the ice supply has long since been withheld. This is true of the piedmont bulbs of Galiano and Lucia glaciers, to the ends of which the effects of even a recent notable advance did not extend. In still other cases, the ends of the bulbs have become almost or even completely separated from the main glacier by wastage of clear ice areas back of the terminus. The piedmont bulb develops during a period of advance; it may linger, in more or less mutilated condition, through a period of stagnation, receiving redevelopment when next an advance of sufficient volume occurs. In other words, it does not necessarily represent an existing state of activity and supply; for, because of the protection of a blanket of ablation moraine, it may long retain its position even in the face of warmth, abundant rainfall and failure of ice supply.

Marginal and Terminal Deposits

Since on the seaward side of the coastal mountains, the ends of so many large glaciers lie in a temperate, rainy climate, the phenomena of terminal and marginal deposit are illustrated with great clearness, throwing much light on the origin of similar phenomena in the deposits of former continental glaciers. Particularly is this true of the piedmont areas, not only because of the wide extent of their margins, but also because they are existing examples of a type of glacier that was formerly common in the mountain regions of both Europe and America. It can not be made a part of this address to consider this subject in detail, interesting and important thought it is.[13] Suffice it to say that in Alaska one may see in process of development both lateral and terminal moraines in great variety of form and composition, from stratified gravel or sand, or clay, to true till; eskers and kames; outwash gravel plains and kettles of various forms and sizes; lacustrine deposits of many kinds and marginal lakes of various origins; marginal channels due to erosion

[13] See Tarr, R. S., "Some Phenomena of the Glacier Margins in the Yakutat Bay Region, Alaska," *Zeitschr. für Gletscherkunde*, Vol. 3, 1908, pp. 81–110; also, "The Yakutat Bay Region, Alaska," U. S. Geol. Survey, Professional Paper 64, 1909.

and the work of marginal streams in deposit; indeed almost the whole series of phenomena which were present along the receding margins of the Pleistocene glaciers. There are phenomena of recession, of advance, and of alternate recession and advance in the course of which soil beds and plant remains were incorporated between distinct sheets of glacial deposits.

Of all the deposits at present being made in association with Alaskan glaciers, those made by the glacial streams are by far the most prominent. During the summer, torrents of water issue from the margins of the glaciers, and, where the ice is stagnant or thin enough for the existence of subglacial tunnels, from the central portions also. These torrents, doubtless esker-building beneath the glacier, spread out over alluvial fans, or broad outwash gravel plains, or long, narrow valley trains, which they are upbuilding by the extensive deposition that is made necessary by the overburdened condition of the streams on their escape from the ice tunnels. Over such a deposit the streams spread in a multitude of anastomosing branches, ever shifting in position as they aggrade their beds in the effort to establish a grade sufficient for the transportation of the sediment load. Within a few miles of the glacier front the slope of the aggrading streams may average 50 or 60 feet to the mile, and close by the glacier even much more than this.

So great is the velocity of the glacial torrents that good-sized stones are dragged along, and one can hear them striking together as they roll on down stream. First the boulders are dropped, then the gravel, then the sand, and with the change in material deposited is an associated change in grade; but throughout their course the grade of the glacial streams is commonly very steep, for they are normally so charged with sediment, and much of the sediment is so coarse, that it quickly settles in a slow current. Schrader says that in its upper course the Klutena River has a grade of 60 feet a mile, then for 28 miles an average grade of 22 feet a mile and a velocity of 14 miles an hour. The Copper River, into which it empties, flows with a velocity of 8 miles an hour.

The Sediment Supply of the Glacial Streams

In volume, slope and sediment load the Alaskan glacier streams are noteworthy. During a period of a few months each year the drainage of a wide area, locked up in the form of snow and ice, is turned into torrents of running water which issue as full-fledged streams, and even as veritable rivers from near the glacier ends. A glacier that is just at the balance between supply and melting furnishes to the streams only that water which is brought down to or near to the ice front; but in a glacier that is receding, there is added to this supply all that which is melted from the ice that is no longer moving forward. Therefore, where, as is so often the case in Alaska, the glaciers are stagnant or receding, the supply of water exceeds the normal.

The impressive volume of sediment, fine and coarse, which the glacial streams are transporting leads the inquiring mind to raise the question as to its origin. Streams having their source in the rainfall are not often so sediment-laden as the glacial streams normally are; indeed, even the exceptional land-supplied streams are rarely as heavily burdened, even for a few days, as the glacial torrents normally are for several months. Particularly is the question of the origin of the finer grained sediment of interest. It is abnormal in quantity as compared with mountain streams in gen-

eral, and yet it comes from a drainage area largely protected by snow and ice against those atmospheric agencies which transform hard rock to fine clay. Can there be any doubt but that the glacier which protects the rock against the atmospheric agencies must attack it with equal or even greater vigor, in order to obtain this vast burden of sediment that the streams bear away?[14]

The Recession of Glaciers in Alaska

Throughout the world the general state of the glaciers is one of recession, with local exceptions; and it is as true of Alaska as of other regions. In the two regions where we have the longest record and the most detailed studies—Glacier Bay and Yakutat Bay—there have been great recessions during the period of observation, the continuation of a still greater earlier recession during the last century or more. For instance, in Yakutat Bay the tidal Nunatak Glacier receded at the rate of over 1,000 feet a year between 1899 and 1906, with a total recession of over a mile; and the near-by Hidden Glacier, ending on the land, receded at about a quarter of this rate. Prior to this observed recession, both Hidden and Nunatak glaciers had been so far advanced that they united and their combined front reached about 20 miles farther out than the present end of Nunatak Glacier, and 10 miles beyond the present terminus of Hidden Glacier. From this advanced position there has been rapid and long-continued recession which was in progress up to 1906 in Hidden Glacier, and up to 1909 in Nunatak Glacier. If the observed rate of recent recession of Nunatak Glacier has been steadily maintained throughout the period, it is to be reckoned as of about a century duration.

[14] See von Engeln, O. D., *Zeitschrift für Gletscherkunde*, Band VI., 1911, pp. 138–144.

In Glacier Bay the phenomena have been closely like those of Yakutat Bay. A long-continued recession had been in progress when the Muir Glacier was studied by Wright in 1886, and by Reid in 1891 and 1892, when Muir Glacier front was about 20 miles further inland than it had been 100 or 150 years before; and Grand Pacific Glacier front was about twice that distance back of the former terminus. Where ice had formerly filled the mountain-walled valley to a depth of 3,000 feet, the fiord waters extended in 1892. This recession has continued since then, being especially noteworthy since 1899; and now (1911) both the Grand Pacific and the Muir Glacier fronts are 9 or 10 miles farther back than in 1892, the average recession being at a rate of not far from 2,500 feet a year for the 19 years; but it is to be noted that the rate has not been regular, and that the greater part of the recession has occurred since 1899. The retreat has continued up to 1911 in all the glaciers of Glacier Bay with the single exception of Rendu Glacier (and a small cascading glacier near it), which has recently advanced about a mile and a half. Glacier Bay has been enlarged no less than 50 square miles by ice recession in a period of 19 years. Assuming an average thickness of 750 to 1,000 feet, the total loss of ice in this period is not less than 6 or 8 cubic miles. But to this must be added that which has been lost by ablation from above the present ice surface; and this is also an enormous amount, for all the outer glacier surfaces, even far back from their fronts, are now much lower than they were in 1892.

While these instances are the most striking of which there are records in Alaska, in our own studies Professor Martin and I have observed scores of other cases, widely separated, where there has been notable recent recession and where it is still in prog-

ress; and many instances have been made known to us by the observations of other workers. Therefore, the commonly accepted conclusion that recession is the general rule among the Alaskan glaciers is fully warranted; yet the rule is by no means invariable. For example, Columbia Glacier began advancing in 1908, and Professor Martin found it still advancing in 1910, while in the same year he observed commencement of advance of several glaciers of different sizes in Prince William Sound and Copper River valley. We know also of recent advance of other Alaskan glaciers, the total known to us to have advanced since 1899 being 43, nine of which are in Yakutat Bay; but some of these 43 advances are exceedingly slight; and 43 glaciers form but a minute proportion of the whole number of Alaskan glaciers. These facts demonstrate that it can not be assumed either that the recession is universal, or that it is not liable to interruption. Too little is known about Alaskan glacier history and about Alaskan climate and its variations to warrant any generalization with regard to the possible future of its glaciers; it is not even certain that the present state of general recession is anything more than an episode.

Advance of Glaciers as a Result of Earthquake Shaking

Of all the recent glacier advances of which we have record in Alaska, by far the most interesting are those of Yakutat Bay. Following the vigorous earthquakes of September, 1899, and, as I have elsewhere endeavored to show,[15] as an indirect result of them has come a series of forward movements and transformations of a very spectacular character, interrupting a period of general recession and affecting even stagnant glaciers and piedmont bulbs. First there came a spasmodic advance of at least two small glaciers, and probably others that we failed to detect on our first expedition in 1905; then, in the interval between September, 1905, and June, 1906, an advance occurred in four larger glaciers; in 1906 and 1907 the Hidden Glacier advanced; in 1909 the still larger Lucia Glacier; and in 1909–10 the Nunatak Glacier advanced. The progressive appearance of the advance, correlated with the length of the glaciers, has been set forth in the following table prepared by Professor Martin:

Name of Glacier	Date of Advance	Approximate Length of of Glacier
Galiano	After 1895 and before 1905	2 or 3 miles
Unnamed Glacier	1901	3 or 4 miles
Haenke	1905–6	6 or 7 miles
Atrevida	1905–6	8 miles
Variegated	1905–6	10 miles
Marvine	1905–6	10 miles (exclusive of portion in Malaspina piedmont area)
Hidden	1906 or 1907	16 or 17 miles
Lucia	1909	17 or 18 miles
Nunatak	1910	20 miles

The advance involved a profound breaking of the glacier surface even where pre-

[15] I have presented this theory in various publications, and in these have given a full statement of the facts and a discussion of their bearing on the theory; so that, in view of the character of this address and its necessary briefness, only a very short and general statement is attempted. See especially Tarr, R. S., "Second Expedition to Yakutat Bay, Alaska," *Bull. Geog. Soc. Philadelphia*, Vol. 5, 1907, pp. 1–14; "Recent Advance of Glaciers in the Yakutat Bay Region, Alaska," *Bull. Geol. Soc. America*, Vol. 18, 1907, pp. 257–286; "The Yakutat Bay Region, Alaska," Professional Paper No. 64, U. S. Geol. Survey, 1909; "The Theory of Advance of Glaciers in Response to Earthquake Shaking," *Zeitschrift für Gletscherkunde*, Vol. 5, 1910, pp. 1–35; also Tarr, R. S., and Martin, Lawrence, "Recent Changes of Level in the Yakutat Bay Region, Alaska," *Bull. Geol. Soc. America*, Vol. 17, 1906, pp. 29–64; "The Yakutat Bay Earthquakes of September, 1899," Professional Paper No. 69, U. S. Geol. Survey, 1912 (in press).

viously smooth and uncrevassed; the lower portion of the glacier was greatly thickened; where unconfined between mountain walls there was a notable spreading at the margins; and the free ends of the glaciers were bodily moved forward. In all cases the transformation was rapid and even spasmodic, requiring a period of but a few months for the complete cycle; and in all cases the advance was quickly followed by relapse into the previous state. In other words, a wave spread down through the glaciers with accompanying thickening, spreading, advance and breaking of the rigid upper ice; but after passage the glacier was left in essentially the same state of activity as before, even though that state had been complete stagnation in parts of the affected area.

In some cases the wave spent its effects in breaking, thickening and spreading a piedmont bulb, with little actual advance; in others, the effects of the thrust being confined by bordering mountain walls, and thereby concentrated on the frontal end, there was notable advance of the terminus. Such an advance is best illustrated in the Hidden Glacier, whose front was pushed forward about two miles; and where the ice front stood in 1906 the glacier was 1,100 feet thick after the advance. During a brief, spasmodic advance, at least a third of a cubic mile of ice moved beyond the 1906 front; and great volumes of ice were also added to the glacier back of the old front, for in 1909 the glacier surface rose to a far greater height than in 1905 and 1906.

The theory put forward to account for this series of glacier advances is that the vigorous earthquakes of September, 1899 shook down such great avalances of snow, ice and rock in the glacier reservoirs as to necessitate a wave of advance that swept down through the glaciers, reaching the terminus of the smaller ice tongues very quickly, and the larger ones at later dates, while up to the period of our last observations, in 1910, the very largest glaciers had not yet responded. Since the cause was a sudden and concentrated addition of large supplies to the glacier reservoirs, the resulting wave was naturally rapid in its passage, and it quickly subsided, while its effects in passing were both spasmodic and extreme.

A study of four seasons discovers only evidence favoring this theory, and since it is an efficient cause, known to have been actually present, while no facts are known to oppose it and a great number favor it, I feel convinced that the earthquake avalanche theory merits the wide acceptance that it has received. It adds a new, and, in favorable regions, probably a very important cause for fluctuations in glacier margins. How widely it may be extended in explanation of other glacier advances remains to be established by future studies; it is not to be expected that it will replace the theory of climatic cause for glacier fluctuations; but it may well be expected to supplement it and perhaps in part replace it in regions of frequent earthquakes.

Local Nature of Recent Great Advances

It is too early to attempt to explain all the known variations in Alaskan glaciers, for as yet the body of fact is limited both as to time and as to area. Yet there are some significant features that are well worthy of consideration. Attention has already been directed to the fact that there has been a very great recent recession of the ice fronts in Glacier Bay and a similar recession in the Yakutat Bay region 150 miles to the northwest. This recession, which has been in progress for the past century or more, is really but part of a cycle in which the glaciers are still receding toward

a former minimum. Having at an earlier period been far advanced, and having held this position for a long time, the glaciers in both regions receded to a stand even farther back than the present ice fronts, and remained there long enough to permit the growth of mature forest; then came an advance pushing the ice fronts forward from 20 to 50 miles. This advance is known to have been of brief duration, for the gravels over which the glaciers advanced were not removed by the ice erosion; and it was quickly succeeded by the rapid recession that has been in progress during most of the period of observation.

So great an advance, followed by so great a recession, might be expected to be part of a general cycle affecting all or a large part of the Alaskan field. Yet such is not the case, for in Prince William Sound, 250 to 300 miles to the west of Yakutat Bay, the recent glacier history has been wholly different. In no case have the glaciers recently had a position far beyond their present fronts, while in some cases it is certain that they are to-day as far out as they have been in a century or two. This is especially clearly seen to be the case in Columbia Glacier, which in 1909 and 1910 was advancing into and destroying a mature forest. Forest also grows on the mountain slopes above the glacier for many miles back from its front, suggesting that this glacier is now in a state of unusual advance analogous to that experienced a century or more ago by glaciers to the southeast. Since there is no reason to suspect that a *general* cause which was operating to bring about glacier advance in the Alaskan coastal region could suffer retardation of a full century in the Prince William Sound region, we are forced to the alternate view that even such great advances and recessions as those proved for the Yakutat and Glacier Bay regions are localized phenomena. Whether due to uplift or depression, to vigorous and repeated earthquake shakings, or to local climatic variations remains yet to be determined.

Cause of the Recent Retreat of Muir Glacier

It has been a generally favorite theory that the remarkable recession of Muir Glacier since 1899 is an indirect result of the great earthquakes of September, 1899. Latterly it has been proposed that the recession is due not to this cause, but to the enlargement of ice area exposed to the sea water and consequently to wastage by iceberg discharge. Neither of these theories, nor the two combined, are either competent or needed to explain the phenomena of recession, though doubtless each has been a factor in it. Granting the maximum disturbance by earthquake shaking, and granting even that the glacier could be broken from surface to bottom, which is highly improbable in view of the nature of ice under pressure, the cracks would certainly heal and the ice become welded in its lower portions soon after the breaking. There would be no basis for the continuation of the effect of the earthquakes for a number of years after the shocks themselves had died out; yet recession has continued for twelve years after the earthquakes. Moreover, recession began many years before the earthquakes, though the rate has been much increased since 1899. As to the theory that the recession is due to the enlarged area of ice exposed to salt water, that is surely an efficient aid in recession; but it does not account for the continuation of notable recession of other glaciers in the region which now have less, rather than greater, area exposed to the salt water. Nor does it account for the excessive wastage along land margins and on ice surfaces back from the fronts.

In view of the fact that the glaciers of Yakutat and Glacier bays have been in a state of rapid recession for a century or more, all that is necessary in explanation of the recession since 1899 is to consider it an accelerated part of this grand retreat which must be due to a deficiency of snow supply following an excess in supply, or an emptying of the glacier reservoirs succeeding a filling of them. Of course, the rate of recession may readily have been temporarily modified by crevassing due to earthquake shaking, or locally modified by variation in exposure to wastage, or checked or increased by variations in precipitation or temperature. These, or any other temporary or local causes, are but minor episodes in the general withdrawal of glaciers which a century or two ago had, for some reason as yet unknown, been made to advance farther than they could maintain their fronts.

Some of the Factors Involved in the Phenomena of Advance and Retreat

Under the simplest of circumstances the advance or retreat of a series of glaciers is a complex phenomenon in which so many factors are involved that a full analysis of them can not be undertaken here. Yet some of the factors stand out with such distinctness that I may take time to briefly point them out. The nature of the glacier terminus is of fundamental importance. If the end of an ice tongue is in water it makes a great difference in the rate both of advance and recession whether the water is salt or fresh, whether it is deep or shallow, whether it is in active movement or is quiet, whether there is or is not a free escape for the icebergs, and whether the relative area of ice cliff is small or great. All these factors are effective in addition to the rate of supply of ice to be discharged. If, on the other hand, the terminus is on the land, there are influences of exposure, of elevation, and of amount of moraine cover, as well as the amount of ice supplied.

Illustration from Yakutat Bay

It is clear that there must be a very great difference, especially in recession, according to whether the ice front is on the land or in the sea, for in the latter position wastage is far more rapid than in the former. This finds clear illustration in the Yakutat Bay region, for during the recent great expansion of the glaciers, a century or more ago, not only were the tidal Nunatak, Turner and Hubbard glaciers caused to advance, but the glaciers ending on the land also pushed forward, presumably at about the same time. Along the margin of Malaspina Glacier, for instance, the same phenomena of overridden gravels and buried forests are discovered as in the area over which Nunatak-Hidden Glacier advanced. But while the tidal glaciers have receded 10 to 20 miles, the recession of Malaspina Glacier has been, at the most, but a fraction of a mile; and in some parts of its moraine-covered margin, on which forest grows, it has remained practically stationary for at least half a century. This extreme difference may possibly be in part due to a more constant maintenance of the ice supply in the Malaspina Glacier, though of this there is no proof; it certainly is *partly* due to the difference in rate of recession of glaciers terminating on the land and in the sea.

Modification of Local Climate as a Result of Advance and Retreat

In interpreting both the cause and the rate of advance or recession of glaciers it is evident that the mere fact of advance encourages advance, while recession encourages continuation of recession. When

a glacier advances, the area of ice surface is increased, and its level rises, while with retreat the glacier surface is lowered and the area of ice is decreased; and if the terminus is in the sea there is a variation in the amount of floating ice with advance or recession. These changes produce a very pronounced effect on local climate, influencing both snowfall and ablation. Though the extent of the influence is naturally variable, it is roughly proportionate to the amount of the advance or retreat and to the area and height to which the variation extends. Other things being equal, the influence of an advance in encouraging advance is greater and more prolonged when the ice ends on the land than when its terminus is in the sea; for on the land the ice spreads farther and remains in position longer. Thus the climatic influence of the last advance of Malaspina Glacier is still dominant, while that of the neighboring Hubbard Glacier has been very greatly reduced by its notable recession.

In illustration of these principles it may be stated that photographs of Hidden Glacier, which in the interval between 1905 and 1909 had advanced two miles and had become greatly thickened, show a very notable difference in the amount of snow on and above the ice. This is undoubtedly due to the double cause of greater snowfall and decreased melting, brought about by a modification of the local climate as a result of the advance. At Muir Glacier, which in the interval between 1892 and 1911 has suffered such excessive recession and lowering of its surface, the climatic difference is also distinctly noticeable in photographs, but with results of exactly the opposite kind. Here there is a smaller area of ice, the surface of that which remains is much lower than formerly, a larger proportion of the surface is covered with moraine or discolored by débris, and the snow-covered area on the mountain slopes is greatly diminished. Without doubt the depth of annual snowfall is markedly decreased, while the amount of ablation is notably increased in 1911, as compared with 1892. Thus when a deficiency of snowfall, or other cause gives rise to a recession, the rate of ablation may come to be considerably in excess of the amount by which the ice supply is deficient, and the rate of retreat therefore may become much more rapid than would be expected from the mere difference in ice supply.

Recession Following Advance

The problem of advance and recession is still further complicated by the apparent manner in which glacier advances take place. As shown by Finsterwalder and others,[16] the Vernagt Glacier of the Tyrol responds to climatic variations by the passage through the glacier of a wave which causes the terminus to move forward, the forward movement being concentrated in a brief period of time. Other glaciers, in the Himalayas, in Patagonia and in Spitz-

[16] Finsterwalder, S., "Der Vernagtferner," *Wissenschaftliche Ergangzungshefte zur Zeitschrift des D. u. O. Alpenvereins*, 1. Band, 1. Heft, Graz, 1897; Anhang, Blumcke, A., und Hess, H., "Die Nachmessungen am Vernagtferner"; Blumcke, A., und Hess, H., "Beobachtungen an den Gletschern des Rofentales," *Mitt. des D. u. O. A.-V.*, Jahrgang 1900, Nr. 4; "Einiges über den Vernagtferner," *ibid.*, Jahrgang 1902, No. 18; "Tiefbohrungen auf dem Hintereisferner," 1902, *ibid.*, Jahrgang 1902, Nr. 21; "Tiefbohrungen am Hintereisferner im Sommer 1908," *Zeitschrift für Gletscherkunde*, Band III., 1909, pp. 232–236; "Tiefbohrungen am Hintereisgletscher," 1909, *ibid.*, Band IV., 1909, pp. 66–70; Hess, H., "Zur Mechanik der Gletschervorstosse," *Petermanns Geogr. Mitt.*, 1902, Heft V.; Hess, H., "Probleme der Gletscherkunde," *Zeitschrift für Gletscherkunde*, Band I., 1906, pp. 241–254.

bergen, whose ends have been rapidly and notably pushed forward are apparently illustrations of the same principle; and because of the peculiar nature of the cause for the wave, the Yakutat Bay glaciers furnish illustrations of an even more spasmodic movement, and a more rapid subsidence of the wave of advance. There are many instances of minor, or minute, advances of glacier fronts; and we also know of a number of cases of noteworthy advances in Alaska and elsewhere. The more notable advances seem to be illustrations of the same principle, that a wave of advance, concentrated on the terminus of the glacier, pushes it far forward; then follows a relative deficiency of supply and consequent retreat. In the recently advanced glaciers of the Yakutat Bay region the subsequent deficiency has been so great that stagnation has immediately followed advance.

We have not yet large enough body of fact to warrant the statement of a law, but such knowledge as we possess indicates that there is reason to expect relatively rapid recession following an advance, because a deficiency of supply follows as a necessary result of the utilization of a part of the ice supply in the progress of the wave of advance. In other words, the reservoir is temporarily depleted by the drain upon it during the advance.

Former Glaciation

The major part of this address has been devoted to the existing glaciers and their recent history, for this has been the field of my most extensive study. But little time remains for a consideration of the former glaciation, and what is said must of necessity be brief, and must deal with only the most general and fundamental points.

Extent of Former Glaciers

It is now a well-known fact that in recent geologic time there has been a very notable expansion of Alaskan glaciers both along the coast and in the interior. The fiords of southeastern Alaska were filled with ice to their seaward entrances, and the same was true as far west as the Alaska Peninsula. Thus there was a vastly greater ice-covered area on the seaward side of the coastal mountains than now exists there. In the interior there was also notable expansion on the inner side of the coastal mountains, on both sides of the Wrangell and Alaska ranges, and in the Endicott Mountains. Elsewhere in the mountains of the interior, even where now there are no living glaciers, there were valley tongues, and perhaps even expanded piedmont bulbs. All this glaciation was, however, purely of the mountain type, and far the greater part of Alaska was untouched by it.

Along the coast there were extensive piedmont glaciers, and there were vast piedmont ice sheets filling the fiords to a depth of several thousand feet, overflowing the low islands and peninsulas now separating them, and discharging icebergs into the ocean. Piedmont glaciers also developed along the inner face of the coastal mountains and on both sides of the Wrangell Mountains, and the Alaska Range.

By far the greatest area of ice in the interior was that which, in its maximum stage, nearly or quite filled the great basin that lies between the coastal mountains, the Wrangell Mountains and the Alaska Range, forming a great *intermont* glacier by the junction of a series of piedmont glaciers. The exact extent and the characteristics of this glacier are not yet determined; and it is not certain that it filled the entire Copper River Basin, though it

probably did, and even extended into the Susitna Valley.

Deposits of Former Glaciers

The deposits of this former glaciation are not usually extensive among the mountains, whence they have easily been removed by subsequent denudation; nor are they very notable in most places along the coast, for there the greater portion of the deposits doubtless lies beneath the sea. Only in a few places, as in the foreland that skirts the seaward base of the Fairweather Range, is there an extensive area of deposit above sea level; elsewhere the general scarcity of glacial deposit is usually striking.

In the interior, on the other hand, and notably in the Copper River Basin, there is a remarkable development of glacial and glacio-fluviatile deposit formed during the period of glaciation and during its stages of advance and of recession, of which the present must be considered a part. Here one finds the greater number of glacial features common to an area of continental glaciation—lake and glacial stream deposits, loess, till, eskers, kames, moraines, and marginal channels are found in perfect development over a wide area. One familiar with glacial deposits in Europe or America finds himself quite at home in the Copper River Basin.

The Period of Expansion

There has not been enough study of the glacial deposits to render it possible to state whether the history of the glaciation in Alaska presents the same complexity as that observed in Europe and eastern America; nor can it even be assumed that the Alaskan glaciation was contemporaneous with the glaciation of these lands. Yet, although very extensive glaciers still exist in Alaska, and although these are certainly the descendants of the former expanded glaciers, it is entirely possible that the time since the maximum expansion is as great as that in other northern lands, such as Norway and Scotland. I can see no noticeable difference either in the extent of post-glacial denudation, or in the weathering of glacial deposits in Alaska and the Alps, or Norway, or Scotland. The greatest expansion of Alaskan glaciers certainly occurred many centuries ago, and may well have been as long ago as the time when the glaciers of the Alps shrank back into the mountain valleys. The vast work performed by glacial erosion in the Alaskan fiords clearly proves that the period of expansion of glaciers was of long duration.

Difference in Extent of Recession

There is one very puzzling condition that renders the solution of the problem of the time of maximum expansion difficult to solve. In southeastern Alaska and in Prince William Sound the tidal glacier fronts now lie from 75 to 100 miles farther back than they were in the period of greatest expansion, and vast areas of land and water have been uncovered by the recession of the glaciers. So also there has been a very large area uncovered by glacier recession in interior Alaska. But in the coastal area between Cross Sound and Prince William Sound, the glaciers of to-day appear to be only slightly less extensive than they were at the maximum. According to G. C. Martin,[17] the present surface of Martin River Glacier is only 600 or 700 feet lower than during the maximum glaciation, while Bering Glacier is only about 200 feet lower; and the horizontal extension of the glaciers at the period of maximum expansion was only very slightly beyond the

[17] Martin, G. C., "Geology and Mineral Resources of the Controller Bay Region, Alaska," Bull. No. 375, U. S. Geol. Survey, 1908, pp. 50–52.

present borders. Malaspina Glacier has shrunk more than the Bering, but even this is far nearer the maximum than the glaciers of Prince William Sound toward the west, or those of the Inside Passage to the southeast, or those of the interior to the north. In the same region with Malaspina Glacier, the expansion of the Nunatak-Hidden Glacier, of a century or more ago, extended to within 10 or 15 miles of the earlier maximum.

From these facts it is evident that locally, near the center of the coastal area of Alaskan glaciation, the present day glaciers are only a little short of their former maximum. This may be due to recent extensive uplift of the mountains in which these glaciers have their source, or to other local causes; or the entire history of Alaskan glaciation may be related to changes in elevation, and wholly unrelated to those causes that gave rise to the development of continental glaciation in Europe and eastern North America. We are not now in possession of a sufficient body of fact to warrant further discussion of this problem.

CONCLUSION

This brief analysis makes it clear that up to the present time only a beginning has been made in the research in the field of Alaskan glaciers and glaciation. Enough has been done, however, to show the existence of interesting and important problems, to permit a few of them to be set forth in concrete form, and to discover facts that have a bearing upon some of them. But there is so much yet to be learned, so many more facts are needed, there is so wide a field that is wholly unknown, and the period of observation is so limited that any one who undertakes to consider the general problems of this broad and complicated field can not but feel appalled at the limitations surrounding his attempt. At best, with all the help that he can obtain from the work of others, he can only hope to make a step toward the understanding of the conditions and problems of this great field. I do not delude myself with the belief that in this address I have done more than this.

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PROFESSOR GEORGE DAVIDSON

IN San Francisco on December 1, 1911, Professor George Davidson quietly ended a long life of active and valuable service to his country. Men of science the world over are expressing their sorrow at his passing, but everywhere there swells also the strong note of pride and satisfaction in the magnificent example which he has given of what may be accomplished by the devotion of a clean, strong life to a chosen field of work. Beginning his independent scientific observations in 1843 as magnetic observer for Girard College, he devoted sixty-eight years of virile manhood to geodesy, geography and astronomy. For fifty years of this long period he was uninterruptedly in the service of the United States Coast and Geodetic Survey. Three years after his retirement in 1895 from the survey he was elected to the professorship of geography in the University of California, with which institution he was connected to the time of his death. This change in his nominal employment made, however, no serious break in the continuity of his life of study and research. The exceptional character of his mental and physical virility is strikingly shown by his election to the faculty of the University of California at the age of 73—eight years beyond the limit usually fixed for the retirement of college professors.

Few men can read the brief sketch which follows without some feeling of surprise that the life of a contemporary should reach so far back into the history of another generation. Born in Nottingham, England, on May 9, 1825, in early boyhood he was brought to the United States by his parents, who settled in